Aortic valve surgery: Marked increases in volume and significant decreases in mechanical valve use—an analysis of 41,227 patients over 5 years from the Society for Cardiothoracic Surgery in Great Britain and Ireland National database

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Objectives: Aortic valve replacement is accepted as a standard treatment for aortic stenosis and regurgitation. To help plan the national requirement for conventional and catheter-based procedures, we have analyzed the Society for Cardiothoracic Surgery in Great Britain and Ireland audit database to look at changes in practice over time.

Methods: All patients undergoing conventional aortic valve replacement with or without coronary artery surgery from April 2004 to March 2009 were included. The main outcome measures were changes in the number, characteristics, operative details, and in-hospital mortality. We have looked particularly at trends and outcomes in elderly and high-risk patients (EuroSCORE of 10 or more) who may now be considered for percutaneous aortic valve insertion.

Results: A total of 41,227 patients underwent aortic valve surgery over 5 years with an in-hospital mortality of 4.1%. The annual number increased from 7396 in 2004-2005 to 9333 in 2008-2009, with significant increases ($P < .0005$) in mean age (68.8-70.2 years), the proportion of patients with aortic stenosis (62.4%-65.1%), octogenarians (13.6%-18.4%), high-risk patients (24.6%-27.7%), and those receiving biological valves (65.4%-77.8%). The incidence of permanent cerebrovascular accident was 1.2% and 1.0% in patients having only an aortic valve replacement. The dialysis rate was 4.5% and the reoperation rate for bleeding was 6.6%. Overall mortality decreased from 4.4% in 2004-2005 to 3.7% in 2008-2009. Survival to a mean follow-up of 2.5 years was 89%.

Conclusions: We have seen a large increase in annual volume of aortic valve replacements, with more patients undergoing surgery for aortic stenosis and an increase in surgery in the elderly and high-risk patients. (J Thorac Cardiovasc Surg 2011;142:776-82)

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Aortic valve replacement (AVR) is a class I indication for surgery for patients with symptomatic severe aortic stenosis or regurgitation.[1] Successful surgery improves both symptoms and life expectancy in these patients. Recently, there have been several developments; there are increasing reports about the longevity of biological valves, and novel treatments of aortic valve disease via catheter-based or transapical approaches are being introduced for high-risk patients.[2,3] Planning transcatheter aortic valve intervention services nationally requires information about the numbers of suitable patients. If conventional surgery is becoming safer, the need for transcatheter aortic valve intervention is less clear. Therefore, to study changes in practice over time and establish clear contemporary outcomes after conventional aortic valve surgery to help inform decision making for high-risk patients, we have analyzed a large national database.

PATIENTS AND METHODS

Since 1994 the Society for Cardiothoracic Surgery of Great Britain and Ireland has been involved with a Central Cardiac Audit database project to

Abbreviations and Acronyms

AVR	= aortic valve replacement
CABG	= coronary artery bypass grafting
CI	= confidence interval
NYHA	= New York Heart Association
STS	= Society of Thoracic Surgeons

which cardiac surgical units submit online encrypted data including preoperative patient characteristics, operative details, and postoperative outcomes (www.ccad.org.uk). Survival data come from the Office of National Statistics. We have analyzed these data for the 5-year time period from April 1, 2004, to March 31, 2009.

We have extracted all patients undergoing aortic valve surgery including those undergoing concomitant coronary artery bypass grafting (CABG). We have excluded patients undergoing other concomitant aortic procedures including those having a procedure for atrial fibrillation. Patients aged less than 18 years of age were also excluded.

We have defined high-risk patients as those with a logistic EuroSCORE[4] of 10 or more. We have looked at the overall incidence, influence on in-hospital mortality, and changes over time of the following preoperative and operative risk factors: sex, age, symptom status (New York Heart Association [NYHA] class), diabetes, operative priority, left ventricular function, renal function, previous cardiac surgery, chronic obstructive pulmonary disease, peripheral vascular disease, atrial fibrillation/flutter, concomitant coronary artery surgery, cardiogenic shock, and body mass index. In-hospital mortality was defined as any death occurring in hospital during the same admission. We have looked at the independent predictors of the in-hospital mortality in this group using logistic regression.

Statistical Analysis

Age is presented as a mean with standard deviation, with 1-way analysis of variance used to test the differences or trend as appropriate. Categorical variables are presented as frequencies and percentages. The χ^2 test was used to assess the associations between the categorical variables unless the variable was dichotomous, in which case Fisher's exact test was used. The χ^2 test for trend (linear-by-linear association test) was used to assess variable trends. Multivariate logistic regression was used to identify independent risk factors for in-hospital mortality. Candidate variables with a P value less than .1 were entered into the regression model. Statistical analyses were performed with SPSS version 18.0 (SPSS, Inc, Chicago, Ill).

RESULTS

Change in Numbers Undergoing AVR and Inpatient Characteristics

A total of 41,227 patients underwent aortic valve surgery during the time period of study. Over the 5 years there was an increase in the number of patients undergoing aortic valve surgery each year from 7396 in 2004-2005 to 9333 in 2008-2009, with a small but statistically significant increase in mean age from 68.8 to 70.2 years old ($P < .0005$) (Table 1). There were significant increases (all $P < .0005$) in the proportion of patients with aortic stenosis (62.4%-65.1%), octogenarians (13.6%-18.4%), and high-risk patients (24.6%-27.7%) There was no significant change in the proportion of patients undergoing concomitant CABG.

In-Hospital Mortality and the Univariate Associations With Mortality

The overall in-hospital mortality was 1700 (4.1%) (Table 2). The mortality for those over the age of 80 was 452 (8.1%) and for patients 85 or older 131 (8.1%). For patients with a logistic EuroSCORE of 10 or more, the mortality was 1042 (9.5%). Over the 5 years there was a small but statistically significant decrease in the overall mortality from 4.4% in 2004-2005 to 3.7% in 2008-2009, with significant decreases for patients with a logistic EuroSCORE of 10 or more (10.8%-8.8%; $P = .032$) and those receiving biological valves (5.1%-4.0%; $P = .008$). The incidences of various risk factors and the univariate association with in-hospital mortality for all patients are shown in Table 3. The statistically significant risk factors include age of 80 years or more, female gender, low ejection fraction, NYHA class III/IV, Canadian Cardiovascular Surgery class III/IV, previous cardiac surgery, diabetes, peripheral vascular disease, nonelective surgery, renal function, chronic obstructive pulmonary disease, absence of sinus rhythm, concomitant coronary artery surgery, valve implant type, body mass index, and cardiogenic shock.

Ratio of Biological to Mechanical Valves

The proportion of patients receiving biological valves increased significantly through the study period from 65.4% in 2004-2005 to 77.8% in 2008-2009 (Table 4). There were increases in the proportion of biological valves inserted in all age groups. For patients over 70 years of age the percentage increased from 87% in 2004-2005 to 95% in 2008-2009, whereas for those under 55 the percentage increased from 18% in 2004-2005 to 25% in 2008-2009.

Comparison of Patients Undergoing Isolated AVR and AVR Plus CABG

A total of 16,684 patients underwent combined AVR and grafts, and 24,543 patients underwent isolated AVR (Table 5). The patients undergoing combined surgery were significantly older (mean age 73.0 vs 66.9 years; $P < .0005$), with a higher proportion (all $P < .0005$) of octogenarians (20.0% vs 13.1%), high-risk patients (48.2% vs 23.3%), patients with aortic stenosis (69.5% vs 59.8%), and those receiving biological valves (82.4% vs 67.0%), and with a significantly lower proportion ($P < .0005$) of women (29.6% vs 43.0%) and those receiving mechanical valves (17.3% vs 32.0%).

In terms of other comorbidities, the incidence of permanent cerebrovascular accident in all 41,227 was 1.2%. In patients who had AVR only the incidence of cerebrovascular accident was 1.0%. The incidence of dialysis among all patients was 4.5% and 3.6% in patients receiving only an AVR. The total reoperation rate for bleeding was 6.6% and the reoperation rate for any reason was 8.2% (Table E1).

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TABLE 1. Changes in patient demographics over time

	Financial year						*P* value for trend
	Total	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	
No. of patients	41,227	7,396	7,816	8,097	8,585	9,333	
Age (y), mean (SD)	69.3 (11.8)	68.8 (11.8)	68.8 (11.8)	69.4 (11.6)	69.5 (12.0)	70.2 (11.6)	<.0005
Female gender, n (row %)	15,495 (37.6%)	2800 (37.9%)	2925 (37.4%)	3022 (37.3%)	3203 (37.3%)	3545 (38.0%)	.874
BMI, n (row %)	27.8 (5.06)	27.4 (4.90)	27.6 (5.04)	27.7 (4.97)	27.9 (5.15)	28.1 (5.05)	<.0005
Impaired LV, n (row %)	12,207 (29.6%)	2234 (30.2%)	2319 (29.7%)	2447 (30.2%)	2552 (29.7%)	2655 (28.4%)	.022
NYHA III-IV, n (row %)	18,934 (45.9%)	3565 (48.2%)	3562 (45.6%)	3707 (45.8%)	3927 (45.7%)	4173 (44.7%)	<.0005
Presence of diabetes, n (row %)	6538 (15.9%)	1022 (13.8%)	1144 (14.6%)	1277 (15.8%)	1479 (17.2%)	1616 (17.3%)	<.0005
Previous cardiac surgery, n (row %)	3530 (8.6%)	662 (9.0%)	672 (8.6%)	722 (8.9%)	701 (8.2%)	773 (8.3%)	.069
Nonelective, n (row %)	10,282 (24.9%)	1891 (25.6%)	2024 (25.9%)	2073 (25.6%)	2208 (25.7%)	2086 (22.4%)	<.0005
Octogenarians, n (row %)	6563 (15.9%)	1007 (13.6%)	1095 (14.0%)	1308 (16.2%)	1433 (16.7%)	1720 (18.4%)	<.0005
Extracardiac arteriopathy, n (row %)	4306 (10.5%)	713 (9.8%)	806 (10.4%)	814 (10.1%)	900 (10.5%)	1073 (11.6%)	<.0005
Absence of sinus rhythm, n (row %)	6008 (14.6%)	1023 (13.8%)	1098 (14.0%)	1181 (14.6%)	1299 (15.1%)	1407 (15.1%)	.004
Renal impairment, n (row%)	1515 (3.7%)	296 (4.0%)	284 (3.6%)	290 (3.6%)	328 (3.8%)	317 (3.4%)	.118
Pulmonary disease, n (row%)	6193 (15.0%)	1054 (14.3%)	1265 (16.2%)	1214 (15.0%)	1244 (14.5%)	1416 (15.2%)	.957
High risk (EuroSCORE > 10) n (row %)	11,043 (26.8%)	1816 (24.6%)	2060 (26.4%)	2225 (27.5%)	2359 (27.5%)	2583 (27.7%)	<.0005
Logistic EuroSCORE > 25	2382 (5.8%)	378 (5.1%)	412 (5.3%)	511 (6.3%)	497 (5.8%)	584 (6.3%)	.001
Aortic stenosis, n (row %)	24,829 (63.7%)	4104 (62.4%)	4408 (63.2%)	4951 (63.4%)	5373 (64.0%)	5993 (65.1%)	<.0005
Biological valve, n (row %)	29,611 (71.8%)	4835 (65.4%)	5341 (68.3%)	5780 (71.4%)	6392 (74.5%)	7263 (77.8%)	<.0005
Concomitant CABG, n (row %)	24,543 (59.5%)	4505 (60.9%)	4618 (59.1%)	4754 (58.7%)	5104 (59.5%)	5562 (59.6%)	.245
Cardiogenic shock, n (row %)	358 (0.9%)	56 (0.9%)	71 (1.0%)	69 (0.9%)	95 (1.2%)	67 (0.7%)	.419

SD, Standard deviation; *BMI,* body mass index; *NYHA,* New York Heart Association; *CABG,* coronary artery bypass grafting.

Independent Risk Factors for In-Hospital Mortality

Multivariate logistic regression was applied to the data. The independent predictors of mortality are shown in Table E2. They include the following, in order of importance of categorical variables: redo surgery, cardiogenic shock, previous cardiac surgery, renal disease, nonelective surgery, concomitant CABG, NYHA class III/IV, EuroSCORE of 10 or more, nonsinus rhythm, female gender, impaired left ventricular function, peripheral vascular disease, and diabetes. Age was also a highly significant risk factor, analyzed as a continuous variable.

Predictors of Out-of-Hospital Mortality

The mean follow-up was 2.4 years and the longest follow-up was 5.2 years. Survival to census was 89%. Univariate associations are shown in Table E3. Survival was significantly impaired by age over 80 years, impaired left ventricular function, NYHA class III/IV, Canadian Cardiovascular Surgery class III/IV, renal disease, previous surgery, and additional grafts with AVR, pulmonary disease, diabetes, hypertension, and cardiogenic shock. The estimated survival of a patient with a biological valve was significantly lower than that of patients with a mechanical valve

Cox regression was applied to the data. The multivariate predictors of survival to census are shown in Table E4. Being male, having a low NYHA score, and absence of diabetes, renal disease, peripheral vascular disease, or cardiogenic shock were all predictors of survival. The hazard ratio for improved survival was 1.46 (95% confidence interval

TABLE 2. The change of in-hospital mortality in different groups over time

		Financial year					*P* value for trend
	Total	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	
Octogenarians, n (%)	452 (6.9%)	84 (8.4%)	73 (6.7%)	95 (7.3%)	98 (6.9%)	102 (6.0%)	.036
High risk, n (%)	1042 (9.5%)	196 (10.8%)	195 (9.5%)	210 (9.5%)	215 (9.1%)	226 (8.8%)	.032
Stenosis, n (%)	972 (3.9%)	185 (4.5%)	176 (4.0%)	201 (4.1%)	205 (3.8%)	205 (3.4%)	.07
Biological valve, n (%)	1333 (4.5%)	248 (5.1%)	246 (4.6%)	257 (4.5%)	289 (4.5%)	293 (4.0%)	.008
Concomitant CABG, n (%)	910 (5.5%)	164 (5.7%)	191 (6.0%)	184 (5.5%)	191 (5.5%)	180 (4.8%)	.053
Mortality (all), n (%)	1700 (4.1%)	326 (4.4%)	330 (4.2%)	342 (4.2%)	353 (4.1%)	349 (3.7%)	.032

CABG, Coronary artery bypass grafting.

TABLE 3. Patient characteristics and univariate association with in-hospital mortality

Risk factor	Patients, n (%)	In-hospital mortality (%)	P value
Age groups			
<80 y	34,631 (84.1%)	3.6%	<.0005
≥80 y	6,543 (15.9%)	6.9%	
Female			
No	25,693 (62.4%)	3.7%	<.0005
Yes	15,479 (37.9%)	4.9%	
Impaired LV			
No	28,993 (70.4%)	2.9%	<.0005
Yes	12,181 (29.6%)	7.0%	
NYHA class III/IV			
No	22,274 (54.1%)	2.5%	<.0005
Yes	18,900 (45.9%)	6.0%	
CCS class III/IV			
No	34,544 (83.9%)	3.7%	<.0005
Yes	6,630 (16.1%)	6.5%	
Renal disease			
No	39,667 (96.3%)	3.8%	<.0005
Yes	1,507 (3.7%)	12.4%	
AVR hemodynamic pathology			
Stenosis	24,795 (63.7%)	3.9%	.007
Regurgitation	5,799 (14.9%)	4.8%	
Mixed	8,319 (21.9%)	4.1%	
Aortic valve implant type			
Mechanical	10,531 (26.1%)	3.1%	<.0005
Biological	29,566 (73.2%)	4.5%	
Homograft/autograft	182 (0.5%)	7.7%	
Concomitant CABG			
No	24,519 (59.5%)	3.2%	<.0005
Yes	16,655 (40.5%)	5.5%	
Previous surgery			
No	37,652 (91.4%)	3.5%	<.0005
Yes	3,522 (8.6%)	10.4%	
Pulmonary disease			
No	34,993 (85.0%)	3.9%	<.0005
Yes	6,181 (15.0%)	5.6%	
Diabetes			
No	34,648 (84.2%)	3.9%	<.0005
Yes	6,526 (15.8%)	5.6%	
Hypertension			
No	16,147 (39.7%)	3.6%	<.0005
Yes	24,512 (60.3%)	4.5%	
PVD			
No	36,643 (89.5%)	3.7%	<.0005
Yes	4,288 (10.5%)	7.8%	
Missing			
Operative priority			
Elective	30,915 (75.1%)	2.9%	<.0005
Urgent/emergency	10,259 (24.9%)	7.8%	
Absence of sinus rhythm			
No	35,179 (85.4%)	3.5%	<.0005
Yes	5,995 (14.6%)	7.9%	
Missing			
Previous MIs			
None	34,507 (87.1%)	3.5%	<.0005
One	4,330 (10.9%)	7.3%	
Two or more	777 (2.0%)	11.7%	
BMI groups			
<35	35,544 (91.8%)	4.1%	.847
≥35	3,195 (8.2%)	4.0%	
Cardiogenic shock			
No	37,648 (99.1%)	3.9%	<.0005
Yes	356 (0.9%)	23.0%	
Missing			

LV, Left ventricle; *NYHA,* New York Heart Association; *CCS,* Canadian Cardiovascular Society; *AVR,* aortic valve replacement; *CABG,* coronary artery bypass grafting; *PVD,* peripheral vascular disease; *MI,* myocardial infarction; *BMI,* body mass index.

[CI], 1.35-1.57) if the patient had a mechanical valve and 1.86 (95% CI, 1.73-1.99) if the patient was younger than 80 years of age.

DISCUSSION

Statement of Principal Findings

We have analyzed a large group of patients undergoing conventional aortic valve surgery. There has been a marked increase in the number of patients undergoing surgery each year, primarily owing to an increase in the number with aortic stenosis. There has been an increase in the mean age, the number of octogenarians, the number of high-risk patients, and the proportion receiving biological valves, particularly in younger patients. The mortality for octogenarians is 8.1% and for high-risk patients, 11.1%, which should act as contemporary benchmarks against which to compare results of novel approaches to implantation of aortic valves and also to plan service provision in the future.

Strengths and Weakness of Study

This is a large study that is based on more than 41,227 patients undergoing AVR, with 6563 (15.9%) being 80 or older and 11,043 (26.8%) being "high risk." The data are collected prospectively in each unit, but units have not been routinely subjected to external validation. However, this database does have the confidence of clinicians and government and has a low incidence of missing data for most fields; as such, we believe it is fit for the purposes to which it has been applied.

In this study, only a small number of units have failed to submit data for single years, and because the missing data from centers are predominantly from the earlier years of the study, it is possible that some of the increase in numbers over time that we have seen is due to more complete data collection. However, after imputation to mitigate the effect of missing operations as described above, we have still seen

TABLE 4. Changes in ratio of biological to mechanical valves in age groups <55, 55 to 60, 60 to 65, 65 to 70, >70 each year

Financial year	Age groups <55 y	55-60 y	60-65 y	65-70 y	>70 y	Total
2004-2005	0.18	0.23	0.37	0.62	0.87	0.65
2005-2006	0.21	0.26	0.42	0.66	0.90	0.68
2006-2007	0.21	0.30	0.44	0.71	0.92	0.71
2007-2008	0.22	0.34	0.50	0.75	0.94	0.74
2008-2009	0.25	0.38	0.55	0.78	0.95	0.78
Total	0.22	0.30	0.46	0.70	0.91	0.72

a 26% increase in numbers. Conversely, there have been some changes in clinical practice over time that will have led to a potential ‘‘undercounting’’; surgical atrial fibrillation procedures for concomitant atrial fibrillation were introduced during the study period and so patients with aortic stenosis and atrial fibrillation would have undergone isolated AVR at the beginning of the study period but may have undergone AVR plus atrial fibrillation ablation (and categorized as AVR plus other) during the later years. However, we think this number would be small and would not change our overall findings.

Strength and Weaknesses Compared With Other Studies

The largest accumulation of isolated AVRs is that in the Society of Thoracic Surgeons (STS) voluntary database. They have reported a total of 108,687 operations up to 2006, with a mean age of 67 years, significantly younger than in our study. This database shows marked differences in patient characteristics to our analysis with higher incidences of female gender (42% vs 37.6%), previous surgery (16.5% vs 8.6%), and aortic stenosis (76% vs 63.7%). The operative mortality in the STS database each year has run between 3% and 4% for isolated AVR and 6% to 7% for combined AVR and CABG surgery, which are in line with the 3.2% and 5.5% mortalities for isolated and combined AVR seen in our study.[5]

TABLE 5. Comparison of patient undergoing isolated AVR and AVR plus CABG

	AVR & CABG	Isolated AVR	*P* value
No. of patients	16,684	24,543	
Age (y), mean (SD)	73.0 (8.34)	66.9 (13.1)	<.0005
Octogenarians, n (%)	3345 (20.0%)	3218 (13.1%)	<.0005
Female, n (%)	4945 (29.6%)	10,550 (43.0%)	<.0005
High risk, n (%)	5322 (48.2%)	5721 (23.3%)	<.0005
Stenosis, n (%)	10,968 (69.5%)	13,861 (59.8%)	<.0005
Previous operation, n (%)	800 (4.8%)	2730 (11.1%)	<.0005
Biological valve, n (%)	13,486 (82.4%)	16,125 (67.0%)	<.0005
Mechanical valve, n (%)	2833 (17.3%)	7704 (32.0%)	<.0005
Mortality, n (%)	910 (5.5%)	790 (3.2%)	<.0005

AVR, Aortic valve replacement; *CABG,* coronary artery bypass grafting; *SD,* standard deviation.

We have seen marked changes in the use of biological valves over the period of study. The literature on the benefits of biological against mechanical valves has been comprehensively covered by the American College of Cardiology/American Heart Association guideline, which states that available randomized study data suggest slight advantages from mechanical valves, but also suggests that there has been a move in the United States toward more biological valve use because of potentially better freedom from structural deterioration in modern generation biological valves, perceived benefits of freedom from long-term anticoagulation, and increasing age of the population undergoing AVR. First-generation stented porcine valves had a relatively high incidence of structural deterioration (around 40% by 18 years), with higher incidences reported in younger patients. The more recent generation of valves has improved freedom from structural deterioration, but the incidence remains related to age at implantation.[6,7] Between 1999 and 2002 the proportion of biological valves inserted in the aortic position for isolated valve replacement in the United States increased from 50% to 65%.[1] A previous report on national data from the United Kingdom contains an analysis of patients undergoing aortic valve surgery with and without coronary artery surgery in the years up to 2003 and shows the start of trends of increased age and increased use of biological valves that we[8] have also observed. In our study between 2004 and 2009, the proportion of biological valves increased markedly over 5 years from 65.4% to 77.8%. It is of interest that there has been an increase in the proportion of biological valves in all age groups, with the percentage of biological increasing from around 87% to nearly 95% in patients aged 70 or older and from 18% to 25% in those aged under 55 years. These changes will be important if the longevity of modern biological valves is not as good as expected. In addition, in the future, with increased uptake of self-management, anticoagulation to more closely control the international normalized ratio, or even mechanical valves in low-risk patients that are maintained on clopidogrel and aspirin rather than warfarin, this trend may reverse.

We do not collect data on the type of biological valves (porcine, pericardial, and others), and it will be important to understand differences in structural deterioration between different types, but this is outside the scope of this study.

To help inform the current debate about high-risk patients with aortic valve disease and novel approaches to aortic valve implantation, we have looked particularly at elderly and high-risk patients, whom we have defined by using the EuroSCORE. There are many studies available analyzing patients purely on the cutoff of increased age, which is known to be a significant predictor of operative risk in patients undergoing AVR.[9,10] Two large studies of results in elderly patients published in 1999 and 2000 showed in-hospital mortalities of around 7% with 8 years' actuarial survival of 46% for isolated AVR and 10.1% for combined AVR and CABG,[11,12] which are higher than those seen in our study. There are numerous single-center studies of AVRs in elderly patients using different age cutoffs,[13-19] that in general show ''satisfactory'' in-hospital and long-term mortality, with good quality of life on follow-up.[14,20] A recent single-institution study of 731 high-risk patients with a EuroSCORE of 7 or more showed that the logistic EuroSCORE significantly overpredicts in-hospital mortality and suggested a good 5-year survival of 72.4%.[6] There is always concern that there is ''publication bias'' from single-center studies, with only good outcomes finding their way into the literature, and as such an overall operative mortality of 4.5% with a mortality for high-risk patients of 9.8% from our large national database should be reassuring, and the results of novel approaches to treating aortic valve disease need to be seen in this context.

Meaning of the Study

This study demonstrates a 26% increase in the number of patients undergoing aortic valve surgery in the United Kingdom over a 5-year period, predominantly owing to an increase in patients with aortic stenosis. We have observed increases in the number of patients in all age groups, but this is most marked in the octogenarians, in whom the numbers have increased by 70%. This implies either that aortic stenosis is becoming more common or that patients are more likely to be diagnosed, referred, and accepted for surgery. We suspect it is the latter, which presumably reflects improvements throughout primary, secondary, and tertiary care in the United Kingdom. The time period of our study shortly follows the introduction of a National Service Framework for coronary artery disease, which gave guidance about processes, standards, and targets for treating patients with ischemic heart disease. It is likely that this initiative has improved overall cardiology services. Symptomatic aortic stenosis has a high mortality if left untreated; thus the increased numbers of patients coming to surgery should be reflected in increased life expectancy and improved quality of life for the population.

The increased use of biological valves in younger age groups is not based on evidence from randomized studies. This strategy has been challenged[21] and it will be important to monitor the outcomes of these patients closely. Of note, we found that on multivariate analysis there was an increased odds of out-of-hospital mortality with a biological valve. This should be interpreted with caution, but several other authors have also reported this outcome in similar such cohort studies.[22-25] The reasons may include preoperative variables that select more frail patients for biological valves that are not captured by the variables that we collected. Alternatively, there may be an adverse association that requires further investigation.

There has also been a doubling in the number of high-risk patients undergoing surgery. These patients have a high mortality of 8.8%, but it should be noted that there has been a significant trend of decreasing operative mortality in these high-risk patients over time. Newer techniques of aortic valve implantation through either transarterial or cardiac transapical routes are now being introduced. These techniques also have a significant mortality and morbidity and uncertain mid to longer outcomes,[26,27] but the data provided in this study will allow results of these novel techniques to be seen against contemporary outcomes of conventional surgery.

Unanswered Questions and Future Research

We have seen a marked increase in the number of patients undergoing AVR in the United Kingdom, but we do not know whether this is due to an increasing incidence of aortic stenosis in a population of increased age or whether it simply reflects unmasking of unmet need by better health care services. It is likely that there are marked variations in the number of operations per million population per year between different regions, and more detailed investigation of geographic variation may be interesting. We have shown marked increases in biological valve usages, particularly in younger patients. The longer-term outcomes of the latest valves in this population are not certain and will need to be monitored closely. We have shown the in-hospital mortality for high-risk patients undergoing conventional AVR, which will be informative as a contemporary benchmark for novel approaches, but it would be useful to describe the midterm and longer-term outcomes of the high-risk patients in more detail along with the clinical factors indicative of poor outcomes in this group.

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TABLE E1. Other outcome measures

	Financial year						*P* value for trend
	Total	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	
No. of patients	41,227	7,396	7,816	8,097	8,585	9,333	
Permanent CVA, n (rate %) all patients	416 (1.2%)	77 (1.4%)	70 (1.1%)	82 (1.2%)	101 (1.3%)	86 (1.0%)	.183
Permanent CVA in patients with AVR only, n (rate %)	201 (1.0%)	29 (0.8%)	33 (0.9%)	39 (0.9%)	54 (1.2%)	46 (0.9%)	.665
Postoperative dialysis, n (rate %) all patients	1516 (4.5%)	213 (3.8%)	260 (4.2%)	298 (4.3%)	426 (5.7%)	319 (4.2%)	<.0005
Postoperative dialysis in patients with AVR only, n (rate %)	721 (3.6%)	108 (3.1%)	108 (1.0%)	145 (3.6%)	207 (4.7%)	153 (3.3%)	.001
In-hospital reoperation, n (rate %)	2941 (8.2%)	523 (8.4%)	544 (8.2%)	581 (8.5%)	607 (8.2%)	686 (8.0%)	.777
Reoperation for bleeding, n (rate %)	2342 (6.6%)	423 (6.8%)	425 (6.4%)	454 (6.6%)	476% (6.4%)	564 (6.5%)	.885

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TABLE E2. Independent predictors for in-hospital mortality

	B-coefficient	Odds ratio (exp B)	95.0% CI		*P* value
NYHA class III/IV	0.501	1.65	1.48	1.84	<.0005
Concomitant CABG	0.524	1.68	1.51	1.88	<.0005
Previous cardiac surgery	0.950	2.58	2.24	2.98	<.0005
Diabetes	0.165	1.18	1.04	1.34	.01
Peripheral vascular disease	0.228	1.26	1.09	1.44	.002
Nonelective surgery	0.563	1.76	1.58	1.95	<.0005
Absence of sinus rhythm	0.441	1.55	1.38	1.75	<.0005
Age (decade)	0.257	1.29	1.20	1.40	<.0005
Impaired LV	0.361	1.43	1.28	1.60	<.0005
Cardiogenic shock	0.952	2.59	1.94	3.45	<.0005
Renal disease	0.804	2.24	1.86	1.04	<.0005
Female	0.361	1.44	1.29	1.60	<.0005
EuroSCORE ≥10	0.476	1.61	1.40	1.86	<.0005

CI, Confidence interval; *NYHA,* New York Heart Association; *CABG,* coronary artery bypass grafting; *LV,* left ventricle.

TABLE E3. Univariate association with survival

Risk factor	Patients	Estimated survival in days (SE)	*P* value
Age groups			
<80 y	27,017	1,686 (3.64)	<.0005
≥80 y	5,182	1,450 (11.2)	
Female			
No	20,121	1,652 (4.49)	.408
Yes	12,078	1,646 (5.87)	
Impaired LV			
No	22,155	1,700 (3.91)	<.0005
Yes	10,044	1,537 (7.35)	
NYHA class III/IV			
No	17,385	1,708 (4.38)	<.0005
Yes	14,814	1,583 (5.73)	
CCS class III/IV			
No	27,159	1,664 (3.800	<.0005
Yes	5,040	1,576 (9.91)	
Renal disease			
No	31,028	1,665 (3.54)	<.0005
Yes	1,171	1,249 (25.4)	
AVR hemodynamic pathology			
Stenosis	2,0415	1,649 (4.50)	.876
Regurgitation	4,716	1,655 (9.20)	
Mixed	5,975	1,649 (8.26)	
Aortic valve implant type			
Nonbiological	8,886	1,735 (5.59)	<.0005
Biological	2,3313	1,614 (4.46)	
Concomitant CABG			
No	19,120	1,695 (4.27)	<.0005
Yes	13079	1583 (6.13)	
Previous surgery			
No	29,519	1,664 (3.63)	
Yes	2,680	1,496 (14.9)	
Pulmonary disease			
No	2,7236	1,666 (3.77)	<.0005
Yes	4,963	1,560 (10.2)	
Diabetes			
No	27,094	1,666 (3.77)	<.0005
Yes	5,105	1,558 (10.3)	
Hypertension			
No	12,637	1,691 (5.24)	<.0005
Yes	19,180	1,623(4.84)	
PVD			
No	29,049	1,670 (3.62)	<.0005
Yes	3,150	1,456 (14.1)	
Operative priority			
Elective	23,793	1,695 (3.82)	<.0005
Urgent/emergency	8,406	1,521 (8.15)	
Absence of sinus rhythm			
No	27,428	1,681 (3.66)	<.0005
Yes	4,771	1,467 (11.3)	
Previous MIs			
None	2,7145	1,673 (3.74)	
One	3,320	1,539 (12.9)	
Two or more	629	1,386 (32.7)	

(Continued)

TABLE E3. Continued

Risk factor	Patients	Estimated survival in days (SE)	*P* value
BMI groups			
<35	29,689	1,648 (3.71)	.165
≥35	2510	1664 (12.9)	
Cardiogenic shock			
No	31,918	1,653 (3.56)	<.0005
Yes	281	1,217 (53.6)	

SE, Standard error; *LV,* left ventricle; *NYHA,* New York Heart Association; *CCS,* Canadian Cardiovascular Society; *AVR,* aortic valve replacement; *CABG,* coronary artery bypass grafting; *PVD,* peripheral vascular disease; *MI,* myocardial infarction; *BMI,* body mass index.

TABLE E4. Independent predictors for out-of-hospital mortality

	B coefficient	Odds ratio exp (B)	95% CI	*P* value
Female gender	0.083	1.086	1.021-1.156	.009
Impaired LV	0.319	1.376	1.293-1.464	<.0005
NYHA class III/IV	0.250	1.283	1.205-1.367	<.0005
CCS class III/IV	–0.034	.966	.893-1.045	.39
Diabetes	0.247	1.280	1.188-1.378	<.0005
Pulmonary disease	0.225	1.253	1.164-1.348	<.0005
Renal disease	0.805	2.236	2.012-2.486	<.0005
Neurological dysfunction	0.104	1.110	.943-1.305	.21
Extracardiac arteriopathy	0.357	1.430	1.318-1.551	<.0005
Absence of sinus rhythm	0.505	1.656	1.545-1.775	<.0005
Cardiogenic shock	0.505	1.656	1.352-2.029	<.0005
Nonelective surgery	0.349	1.418	1.331-1.511	<.0005
Redo surgery	0.567	1.763	1.612-1.928	<.0005
BMI 35 or more	0.009	1.009	.897-1.134	.88
Additional CABG surgery	0.318	1.374	1.289-1.464	<.0005
Biological valve	0.378	1.460	1.351-1.578	<.0005
> 80 y	0.619	1.856	1.732-1.990	<.0005
EuroSCORE > 10	0.476	1.609	1.483-1.746	<.0005

CI, Confidence interval; *LV,* left ventricle; *NYHA,* New York Heart Association; *CCS,* Canadian Cardiovascular Society; *BMI,* body mass index; *CABG,* coronary artery bypass grafting.